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A Practical Test of the Copper Sulphate Method for the Removal of Micro-Organisms From Water

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A PRACTICAL TEST OF THE COPPER SULPHATE METHOD FOR THE REMOVAL OF MICRO-ORGANISMS FROM WATER.

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In Bulletin No. 64, Bureau of Plant Industry, U. S. Department of Agriculture, Dr. George T. Moore and Mr. Karl F. Kellerman published in May, 1904, a method for destroying or preventing the growth of algae and certain pathogenic bacteria in water supplies by the use of copper sulphate. The method was based on a thorough review of the subject of the toxicology of copper, extended laboratory experiments under different conditions upon the action of copper sulphate on various micro-organisms, certain bacteria and such higher forms as fish that might be influenced by its presence. In addition they gave the results of several practical applications in reservoirs of moderate size and a considerable experience in its application to the water of cress beds.

During the past summer numerous practical applications of the method have been made either by Dr. Moore and Mr. Kellerman or with their advice, as well as by independent workers, the results of most of which are as yet unavailable.

The method is one which has caused general interest as, heretofore, all that could be hoped for, even with a regular and systematic microscopical examination of the water, was to be able to avoid as far as possible growths of micro-organisms by drawing the water from such part of the reservoir or from such depth as was found to be least infected with growths. This was possible, as a rule, only in the larger reservoirs so constructed that water could be drawn from different depths and in cases where the growth had a somewhat localized vertical distribution. Little help was offered in the more numerous shallow reservoirs in which growths are most likely to develop in greatest abundance, unless the system consisted of several reservoirs and the infected reservoir could be temporarily cut out of the supply.

The following account is of a practical test of the method on the two storage reservoirs of the Greenwich, Conn., Water Company, made with the advice of Dr. Moore and Mr. Kellerman, and is offered in the hope of enlisting interest in the trial of a method which seems to promise much and as a record of one of the many results that must be collected before comparisons can be made which will lead to a complete

understanding of the possibilities and limitations of the method and the best method of applying it.

The reservoirs are situated at about the center of the township of Greenwich, four and five miles north of the most populous part and are used also as a source of supply for Port Chester and part of Rye. They are fed with surface water and to some extent from springs, have but small and short influent streams and are situated in adjoining drainage areas. Most of the land for some distance back from the shore is owned or controlled by the water company.

ROCKWOOD RESERVOIR.

The upper or Rockwood reservoir has an area of 93 acres with about 7 of shallow flowage, an average depth of 20 feet and a capacity, when filled to the overflow at an elevation of 323 feet, of 325,000,000 gallons. The drainage area contains about one square mile and is hilly and partly under cultivation. About the upper tenth is cut off from the main body by a causeway without other connection than through the loose stone work and filling. The reservoir was formed in 1893 by building two dams or dykes and without removing surface soil from the meadow land and pasture which was flooded. Trees that were within the area of the reservoir were cut near the ground and the stumps mainly left, some of which are exposed at low water.

PUTNAM RESERVOIR.

The lower or Putnam reservoir has an area of about 100 acres with four or more of shallow flowage, an average depth of 15 to 20 feet and a capacity when filled to the overflow at an elevation of 290.5 feet of 300,000,000 gallons. The drainage area contains about two and a half square miles and a small influent stream brings considerable water at certain seasons from the upper part of this area, which is hilly, about one-third wooded and the remainder partly under cultivation.

This is the older of the two reservoirs, upon which work was commenced in 1879 and an additional storage capacity obtained by raising the elevation of the dam in 1887. No surface loam was removed.

The water of each reservoir has given more or less trouble in the past by supporting considerable growths of floating micro-organisms, and every spring there has been, especially in Rockwood reservoir, a large development of the larger forms of *Spirogyra* and *Conferva*.

The microscopical examination of monthly samples from Rockwood reservoir for 1896 showed a considerable growth of *Synedra* between January and May with a maximum growth in April, of *Peridinium* between January and May and the presence of a growth of *Dinobryon*

throughout the year except during May and June, with very large numbers during August and September.

The microscopical examination of samples from Putnam reservoir for 1898 showed the presence of a considerable growth of *Synedra* from January to August, of *Anabæna* from July to November, with the greatest development during August, of *Uroglena* from August to November, reaching highest numbers in September and October and of *Dinobryon* between February and July, with particularly high numbers during May and June.

Water from each reservoir flows by gravity through separate pipes to a filter-house some distance below Putnam reservoir, where all the water is treated by mechanical filtration before it enters the distributing mains.

The filtration plant consists of four vertical tanks, each ten feet in diameter, and two horizontal tanks each ten feet in diameter and twenty feet long, giving a combined capacity of two million gallons or more per day.

At the time of undertaking the experiments about 3,000,000 gallons per day were being drawn from the two reservoirs, about half of which was filtered after treatment with 1.4 grains of alum per gallon, and the remainder was used in washing the filters, which was done thoroughly once every 24 hours. Later the amount of alum was reduced somewhat, and an attempt made to reduce the amount of water used in washing the filters.

The alkalinity of the water varied between 13.8 and 15.6 parts of calcium carbonate per 1,000,000, and was more than was necessary to react with the copper sulphate and the alum in the subsequent mechanical filtration. Copper suphate was added according to the method suggested by Dr. Moore, by suspending it from the boat in burlap bags, each containing 25 pounds, to which a fresh charge was added when the first lot was dissolved to from 5 to 8 pounds.

From one to three bags were used at a time according to the nature or extent of the growth present in the part of the resevoir under treatment, as determined by inspection or previous microscopical examination. Most attention was given to making the addition along the shore and in the bays and shallow flowage areas, which seemed to be the important breeding places of growths. Generally a run of several hundred feet was made along the shore to some fixed point, then across and down the opposite shore to a fixed point and again across to the point left on the shore first treated, thus making from twelve to twenty trips across and frequently additional trips across at the lower or wider part of the reservoir if growths were abundant.

The time required for making the application was two and a half hours for 250 pounds for the three additions of this amount and three hours for 350 pounds, or about fifty-five minutes for each hundred pounds.

The copper sulphate is generally spoken of as being precipitated after being dissolved in the water, but it is a question how far this is the case, except as it unites with the organisms and is precipitated with them after their death. A mixture of copper sulphate with water having the character of that of these reservoirs containing as much as 1 part per 1,000,000 will give no precipitate on standing or will this amount give a precipitate of copper in any of the forms in which copper is ordinarily precipitated in testing for its presence, as shown by laboratory tests by Dr. H. E. Smith, or would any precipitate be expected at this dilution if the solubility of the different forms of copper is considered. This makes it necessary to evaporate a considerable amount of the water to a very small volume to be able to test for the presence of copper in the water after treatment.

It must be borne in mind, however, that as originally applied from the suspended bags, the copper sulphate has gone into solution in really a small volume and this concentrated solution is readily traceable as a colored streak as the boat progresses. This is usually clear, but in certain shallow parts of the reservoir appeared somewhat turbid, which may have meant precipitation or merely the presence of a greater quantity of organisms which acted to reflect the light against the blue colored solution as a back ground.

Calculated from the distance along the shore and the number of times that the reservoir was crossed, and using the average cross section of the number of bags used, it appears that the sulphate actually gave a solution in the line of the boat of about one part to 250 of water when adding the amount calculated to make one part in 5,000,000.

From this line of strong solution mingling takes place vertically by settling and laterally by the action of the wind and the forward motion of the water as the result of drawing from the reservoir at the dam. But one reservoir was treated at a time, and following each treatment the reservoir was not drawn upon for two days.

Copper sulphate was added to the extent of one part to 250 as calculated above to 1.5 liters of unfiltered and filtered water collected on December 19th, from Rockwood reservoir when it contained organisms amounting to 4389 standard units per c.c, mainly of *Dinobryon* and *Uroglena*.

In each case a considerable flocculent precipitate, colored by the copper, was formed, which settled slowly carrying down all organisms

in the unfiltered sample and leaving the water above perfectly clear. Enough was not obtainable to furnish material for a detailed study as to the nature of the combination formed between the copper and the organisms.

TREATMENT OF ROCKWOOD RESERVOIR.

On first visiting the reservoir on July 11th, it was found to have been drawn down about three feet, thus reducing its contents to 235,000,000 gallons. The spring growth of *Spirogyra* and *Conferva,* which was particularly abundant at the lower end of the reservoir had become discolored and had either risen or was rapidly rising to the surface and being distributed by the action of the wind. This was found to contain little more than the sheath of the *Spirogyra* and *Conferva,* but mixed with it were other forms especially cyanophyceæ among which were large amounts of *Anabaena* flos aqua in a developing stage, which seemed likely to become the next growth of importance. Practically all of these patches of algae growths that had risen to the surface were collected by skimming from the surface or by scraping it from the bottom of the shallow portions which had been exposed as the result of drawing down the water.

At this time there were only moderate growths of floating forms and these were rather more abundant at the upper end of the reservoir and near the dam. Infusoria constituted a considerable part of the growth and *Chlamydomonas,* which developed so as to be the main cause of trouble throughout the remainder of the summer, was present in the portion of the reservoir above the causeway to the extent of 95 standard units per cc. Cyanophyceæ, while present in the patches of dead algae rising to the surface were not found free in the water. Another set of samples taken on July 26th the day of making the first application of one part of copper sulphate to 5,000,000, but before adding it, showed that during the interval an increase had taken place throughout the reservoir, the average of total organisms from four points in the reservoir being 452. *Anabaena* was not present, although other forms of the cyanophyceæ had developed to a slight extent. *Chlamydomonas* was present throughout the reservoir, but not in large numbers, the average being 31. Rotifera were present in considerable numbers, the average being 122. Bacteria were present to the extent of from 58 to 204 per cc. in different parts of the reservoir, being most abundant at the upper end and at the dam, the average for the four points of collection being 137.

On July 30th, four days after adding the copper sulphate to the extent of one part to 5,000,000 the average of the total organisms had

dropped to 119, showing a decrease of about 74 per cent; Cyanophyceæ were absent save for the finding of a single piece of *Microcystis*. Diatomaceæ were reduced about 70 per cent, infusoria 85 per cent and the *Chlamydomonas* while present showed a temporary reduction of 80 per cent. Chlorophyceæ showed a reduction of only about 10 per cent and from 20 to 30 standard units of *Sphaerozosma* and *Protococcus* were present.

The bacteria were increased from an average of 117 to 2737 or about 23.5 times the number before treatment. The numbers from the four points of collection varied from 1800 to 4000.

On August 9th, two weeks after treatment, a single sample was taken near the dam which showed that the bacteria had decreased to 420 as compared with 3,000 four days after treatment and 189 before treatment. Total organisms had increased to 194 from 91 and the infusoria to 63 from 16, of which 53 were *Chlamydomonas*. As the difficulty from organisms and especially from *Chlamydomonas* continued, another application of one part to 5,000,000 of copper sulphate was made on August 23d, making the total amount added one part to 2,500,000. Before making this application another set of samples was taken from the usual four stations, which showed that the average of the total organisms had increased to 599. Diatomaceæ had increased to 198, chlorophyceæ to 107. Cyanophyceæ, represented by *Microcystis* alone showed an average of 28 and infusoria 115, of which 101 were *Chlamydomonas*, which were less abundant at the dam than elsewhere.

On August 26th, three days after the application, the average of total organisms from two of the stations was 200, a reduction of 67 per cent, of infusoria 59, of which 45 were *Chlamydomonas*, a reduction of 49 per cent. Diatomaceæ were reduced 80 per cent, chlorophyceæ 50 per cent and cyanophyceæ were absent. A sample taken at the dam on August 29th, three days later, showed little change.

The only form present after the first treatment that caused trouble was the *Chlamydomonas* and, as the authors of the method had found by experiment that this form was very resistant to the action of copper sulphate, one part to 5,000 killing but few after the prolonged treatment of a week and as the account of the treatment of the Elmira, N. Y., reservoir with one and one-third parts per 1,000,000 seemed to show that this amount killed certain forms of fish and pollywogs, it was deemed better not to add more copper sulphate which we felt would not serve to kill the *Chlamydomonas* unless added in quantities greater than it was thought best to add. *Chlamydomonas* continued to give considerable trouble during the early au-

tumn imparting its peculiarly sharp and unpleasant odor to the water to such an extent that it was not entirely removed by filtration, but a sample taken early in November showed that it had finally disappeared.

A sample taken on December 19th, when the water of the reservoir was very low and covered with ice, showed total organisms 4389, of which 4165 were infusoria, 2812 being *Dinobyron* and 1287 *Uroglena.* As *Uroglena* is believed to be killed promptly by the presence of one part of copper sulphate to 2,500,000 and experiments have shown that it is practically all killed after sixteen hours by the presence of one part to 5,000,000 or even one part to 10,000,000, the presence of this growth speaks against much of the copper from the summer treatment remaining in the reservoir in an active form.

I have advised adding copper sulphate dissolved from bags through holes in the ice along the long narrow line of the reservoir, trusting to the forward movement of the water due to drawing from the lower end to effect mixing with the water.

TREATMENT OF PUTNAM RESERVOIR.

On first visiting the reservoir on July 11th, the total organisms were found to vary between 398 and 866, the average of four samples from different points being 691. More than half of these were diatomaceæ, mainly *Tabellaria.* Cyanophyceæ were present throughout the reservoir, the average being 62, with *Protococcus* the most abundant form. Cyanophaceæ were absent save for a little *Coelosphaerium* at the upper end of the reservoir. Infusoria were present in numbers varying from 103 to 297, the average being 167, about half of which were *Peridinium.*

Copper sulphate was added to the extent of one part to 5,000,000 on July 30th. Before making the addition, samples were taken from the upper part of the reservoir and near the dam, which showed that the average of total organisms had increased to 1510. The diatomaceæ had increased to an average of 1202, most of which were *Tabellaria,* chlorophyceæ had decreased to 32 and infusoria to 19, the growth of *Peridinium* having largely disappeared. Cyanophyceæ had increased to an average of 256, the growth being mainly one of *Anabaena gigantica* which was present throughout the reservoir and amounted to 250 near the dam.

The water weeds which were abundant especially in the shallow bays on the west side of the reservoir were thickly covered with gelatinous masses having a slight green color under the hand lens and shown by the microscope to be composed of nostoc or masses of bluish

green filaments, representing a developing stage. The bacteria were low the average being but 87 per c. c. On August 9th, ten days after the treatment the total organisms had decreased to an average of 656 or a reduction of 56% while the water near the dam showed a reduction of 78%. The diatomaceaæ had decreased to an average of 206 or a reduction of 83%. Chlorophyceæ had increased from 32 to 232, *Protococcus* and *Dictiosphaerium* being most abundant. Infusoria had increased from an average of 19 to 199, *Trachelomonas* being most abundant and amounting to 283 at the upper part of the reservoir. Cyanophyceae had decreased to an average of 10 or about 96% and the growth of *Anabaena* had entirely disappeared and the large growth of nostoc on the water weeds was nearly gone. Bacteria had increased from an average of 87 to 49 per cc., and it is possible that during the interval they may have been even higher.

A set taken August 23rd showed an increase of total organisms to an average of 1159, due mainly to an increase in the growth of *Tabellaria.* Cyanophyceæ were entirely absent in the lower part of the reservoir and were represented by only a small amount of *Microcystis* in the upper part. Infusoria had decreased, due to the disappearance of the growth of *Trachelomonas,* but *Chlamydomonas* had appeared to the extent of about 25 in all parts of the reservoir.

A second application of copper sulphate of one part to 5,000,000, making in all one part to 2,500,000, was made on August 26th. Before making the application, a set of samples was taken which showed an average of total organisms of 2159 or about double the number present but three days before, due to a large increase in the growth of *Tabellaria.* The chlorophyceæ showed an average of 230, infusoria an average of 37, of which 27 were *Chlamydomonas* and cyanophyceæ were absent. Bacteria had decreased to an average of 141 per cc.

On August 29th, three days after the treatment, a sample taken at the dam showed total organisms 1117 or a reduction of about 45 per cent, chlorophyceae showed 211 or a reduction of only 8 per cent, cyanophyceae continued absent and the infusoria showed 37 or the same number as before the second treatment, 20 of which were *Chlamydomonas.*

While the *Chlamydomonas* was not removed by the two applications of copper sulphate, the growth did not assume the proportions of the one in Rockwood reservoir and the water of this reservoir remained such that, with the filtration, there has been little if any cause for complaint. A sample taken on December 19th showed but a moderate growth, the total amounting to 246, with infusoria 66, of which 44

were *Cryptomonas* and no *Chlamydomonas.* The few chlorophyceæ amounted to 43.

The rather wide variations in the amount of amorphous matter in the samples is, I believe, to be accounted for wholly by the action of the wind which caused material from the bottom of the rather shallow reservoirs to be brought up and mingled throughout the water of the reservoir, even to the extent of causing the turbidity as determined by disc readings to vary widely on different days. In no case was the nature of the amorphous matter such as to indicate that it was composed mainly of the recently killed organisms as the result of the sulphate treatment.

It is useless to attempt to draw general conclusions from such comparatively limited data from experiments on only two reservoirs containing water of similar character, as it is by no means certain that similar growths in water of a different character would be acted upon in the same way by similar treatment.

Certain facts, however, are so marked as to lead to the belief that they represent general characteristics and may be expected under all conditions.

The most marked of these is the apparent great susceptibility of the cyanophyceae even to small quantities as shown by the prompt and complete disappearance of the considerable growth of *Anabaena* which was uniformly distributed throughout the entire water of Putnam reservoir by the single addition of copper sulphate to the extent of one part to 5,000,000 and the rapid disappearance of the nostic form from the water weeds by the same addition, a growth which I believe represented a developing stage and which would soon have been scattered throughout the reservoir.

As growths of cyanophyceæ are of frequent occurrence, often reaching large numbers and nearly always impairing the character of the water by imparting during the period of growth as well as of decay a characteristic odor and taste, commonly known as the "pig-pen" odor, the method would seem to afford an easy way of quickly removing objectionable growths of this kind or of preventing them in case regular microscopical examinations are made which forecast their appearance.

While an opportunity was not offered to try the method on large growths of chlorophyceæ, it has been a matter of surprise that such as were present were apparently but little influenced and in a few cases developed to some extent within a few days of the time of the treatment.

Both diatomacæ and infusoria appear in every case to have been reduced temporarily by the addition of such amounts as were used, thus holding them temporarily in check. The amount added was, however, insufficient to more than retard their growth, and after a short time they increased. The infusoria appeared to be less active immediately after a treatment, as seen in the microscopic examination.

It is even a question whether certain of the infusoria, as th *Chlamydomonas* were not assisted in their development by the addition of such a quantity of sulphate that, while it did not materially decrease their numbers, proved fatal to other forms, thus providing them with an abundant food supply.

The temporary increase in the number of bacteria may readily be accounted for in the same way. It was not expected that they would be killed by the amount of copper sulphate used, which, however, was sufficient to kill a great many of the micro organisms, thus converting these into available food for the bacteria. The results are given in a concise form on the two following tables.

ROCKWOOD RESERVOIR, GREENWICH, CONN., WATER COMPANY.

ORGANISMS AND AMORPHOUS MATTER EXPRESSED IN STANDARD UNITS PER C.C.

One standard unit is a square field 20μ on a side.

	1904.	Total Organisms.	Diatomaceae. Total.	Diatomaceae.	Chlorophyceae. Total.	Chlorophyceae.	Cyanophyceae. Total.	Cyanophyceae.	Infusoria. Total.	Infusoria.	Rhizopoda.	Rotifera.	Amorphous.	Alkalinity.	Bacteria per c. c.	Temp. of water.
Above causeway	July 11	379	45	Navicula 45	21	....	0	....	228	Chlamydomonas 95	10	75	405	15.2	......	25.5°C
Below causeway	" 11	390	86	Melosira 50	.....	....	0	....	159	Chlamydomonas 95	0	132	427	15.0	......	25.5
Middle of reservoir......	" 11	193	98	Melosira 62	6	....	0	....	89	....	0	0	417	14.0	......	25.5
At dam	" 11	542	93	Melosira 53	28	Conferva 25	0	....	119	Peridinium 88	15	293	290	14.0	......	25.5
Average...........	....	378	105	....	14	....	0	....	143	....	7	125	......	......	......	......
Above causeway	July 26	458	53	Melosira 25	88	Sphaerozosma 63	25	Coelosphaeri'm 13	132	Chlamydomonas 19; Peridinium 62	0	148	427	14.6	204	23.6
Below calseway	" 26	437	87	Melosira 63	39	Staurastrum 19	25	Microcystis 25	172	Chlamydomonas 20; Peridinium 88	0	118	506	13.6	58	23.6
Middle of reservoir......	" 26	531	98	Melosira 83	118	Micrasterias 68	38	Microcystis 25	140	Chlamydomonas 3; Peridinium 75	0	140	418	13.8	99	23.6
At dam	" 26	384	58	Melosira 38	22	Staurastrum 12	25	Microcystis 25	201	Chlamydomonas 93	0	80	433	14.0	189	23.7
Average...........	....	452	74	....	66	....	28	....	161	....	0	122	......	......	137	......

350 pounds copper sulphate added (= 1 part to 5,000,000) on July 26th after taking above samples.

	1904.	Total Organisms.	Diatomaceae. Total.	Diatomaceae.	Chlorophyceae. Total.	Chlorophyceae.	Cyanophyceae. Total	Cyanophyceae.	Infusoria. Total.	Infusoria.	Rhizopoda.	Rotifera.	Amorphous.	Alkalinity.	Bacteria per c c.	Temp. of water.
Above causeway	July 30	139	50	Melosira 38	57	Gloeocystis 20	0	....	32	Chlamydomonas 5	0	0	438	14.0	1800	25.0
Below causeway	" 30	176	13	Navicula 13	84	Sphaerozosma 28	0	....	39	{ Chlamydomonas 9 Glenodinium 20	0	30	470	14.0	2150	25.0
Middle of reservoir......	" 30	72	15	Navicula 8	46	....	0	....	12	{ Chlamydomonas 4 Trachelomonas 8	0	0	348	14.0	4000	24.5
At dam	" 30	91	15	Navicula 10	50	Sphaerozosma 25	10	Microcystis 10	16	Chlamydomonas 6	0	0	277	14.0	3000	24.5
Average...........	....	119	22	....	59	....	3	....	25	....	0	8	......	......	2737	......
At dam	Aug. 9	194	30	Melosira 23	51	Protococcus 23	0	....	63	Chlamydomonas 53	0	50	415	14.0	420	24.5
Above causeway	" 23	509	115	Melosira 88	203	{ Dictiosphaeri'm 45 Sphaerozosma 40	38	Microcystis 38	57	Chlamydomonas 34	0	68	787	14.0	......	22.0
Below causeway	" 23	1025	248	Navicula 245	106	Dictiosphaerium 38	75	Microcystis 75	234	Chlamydomonas 226	0	358	2512	15.0	......	22.0
Middle of reservoir......	23	402	183	Navicula 168	91	Gloeocystis 25	0	....	112	Chlamydomonas 107	0	0	570	15.0	......	23.0
At dam	" 23	447	245	Navicula 220	29	....	0	....	55	Chlamydomonas 35	0	110	552	15.0	......	23.5
Average...........	....	599	198	....	107	....	28	....	115	....	0	134	......	......	......	......
250 pounds copper sulphate added (=1 part to 5,000,000) on Aug. 9th after taking above samples.																
Below causeway	Aug. 26	237	48	Navicula 23	35	Sphaerozosma 8	0	....	62	Chlamydomonas 35	0	80	140	......	257	23.0
At dam	" 26	163	27	Navicula 15	18	Gloeocystis 10	0	....	56	Chlamydomonas 56	0	60	2225	......	558	23.0
Average...........	....	200	37	....	26	....	0	....	59	....	0	70	......	......	408	......
At dam	Aug. 29	225	90	Navicula 88	40	....	0	....	45	Chlamydomonas 43	0	50	1750	......	......	......

PUTNAM RESERVOIR, GREENWICH, CONN., WATER COMPANY.

ORGANISMS AND AMORPHOUS MATTER EXPRESSED IN STANDARD UNITS PER C.C.

One standard unit is a square field 20μ on a side.

	1904.		Total Organisms.	Diatomaceae. Total.	Diatomaceae.	Chlorophyceae. Total.	Chlorophyceae.	Cyanophyceae. Total.	Cyanophyceae.	Infusoria. Total.	Infusoria.	Rhizopoda.	Rotifera.	Amorphous.	Alkalinity.	Bacteria per c. c.	Temp. of water.
Upper part, opp. point...	July	11	398	90	Melosira 50	39	Eudorina 20	70	Coelosphæri'm 50	103	Peridinium 38	0	60	225	14.0	......	25.5°C
Middle of reservoir......	"	11	660	480	Tabellaria 355	65	Pandorina 40	0	....	100	Peridinium 75	0	0	375	18.0	......	25.5
Opp. ice house point....	"	11	839	470	Tabellaria 370	100	Protococcus 50	0	....	169	Peridinium 75	0	100	760	15.2	......	25.5
At dam	"	11	866	457	Tabellaria 392	63	Protococcus 25	0	....	397	Peridinium 188	0	50	427	15.0	......	25.5
Average...........	....		691	374	....	62	....	17	....	167	....	0	53	......	......	......	......
Upper part, opp. point...	July	30	1005	755	Tabellaria 742	30	Protococcus 23	200	Anabæna 138	20	Trachelomonas 15	0	0	233	14.0	90	25.5
At dam	"	30	2015	1648	Tabellaria 1560	34	....	313	Anabæna 250	18	....	0	0	268	14.4	84	25.0
Average..........	....		1510	1202	....	32	....	256	....	19	....	0	0	......	......	87	......

250 pounds copper sulphate added (= 1 part to 5,000,000) on July 30th.

PUTNAM RESERVOIR, GREENWICH, CONN., WATER COMPANY—Concluded.

	1904.	Total Organisms.	Diatomaceae. Total.	Diatomaceae.	Chlorophyceae. Total	Chlorophyceae.	Cyanophyceae. Total	Cyanophyceae.	Infusoria. Total	Infusoria.	Rhizopoda.	Rotifera.	Amorphous.	Alkalinity.	Bacteria per c c.	Temp. of water.
Upper part, opp. point...	Aug. 9	861	239	Tabellaria 138	241	Dictiosphaerium 83	8	Oscillaria 8	354	Trachelomonas 283	0	30	562	14.8	650	24.5
At dam	" 9	451	173	Tabellaria 155	223	Protococcus 120	13	Microcystis 13	44	Trachelomonas 20	0	0	220	14.4	333	24.5
Average...........	....	656	206	....	232	....	11	....	199	....	0	15	......	......	491	......
Upper part, opp. point...	Aug. 23	1121	865	Tabellaria 831	105	Staurastrum 56	25	Microcystis 25	78	Chlamydomonas 25	0	50	757	15.6	......	23.0
At dam	" 23	1198	1104	Tabellaria 952	92	Staurastrum 38	0	....	64	Chlamydomonas 24	0	38	305	15.6	......	23.0
Average...........	....	1159	923	....	99	....	13	....	71	....	0	44	......	......	......	......
Upper part, opp. point...	Aug. 26	2307	1916	Tabellaria 1803	311	Staurastrum 181	0	....	30	{ Chlamydomonas 1, Trachelomonas 28 }	0	60	675	......	151	24.0
At dam	" 26	2011	1812	Tabellaria 1700	150	Staurastrum 85	0	....	44	Chlamydomonas 26	0	0	520	......	131	23.5
Average...........	....	2159	1864	....	230	....	0	....	37	....	0	30	......	......	141	......
250 pounds copper sulphate added (= 1 part to 5,000,000) on Aug. 26th.																
At dam	Aug. 29	1117	839	Tabellaria 795	211	Staurastrum 119	0	....	37	{ Chlamydomonas 20, Trachelomonas 15 }	0	30	625	......	......	......